METHODS AND APPARATUS FOR SCOUT-BASED CARDIAC CALCIFICATION SCORING

BACKGROUND OF THE INVENTION

This invention relates generally to methods and apparatus for cardiac CT imaging, and more particularly to methods and apparatus that minimize an impact of heart motion in collecting calcification data from coronary images.

In at least one known computed tomography (CT) imaging system configuration, an x-ray source projects a fan-shaped beam which is collimated to lie within an X-Y plane of a Cartesian coordinate system and generally referred to as the "imaging plane". The x-ray beam passes through the object being imaged, such as a patient. The beam, after being attenuated by the object, impinges upon an array of radiation detectors. The intensity of the attenuated beam radiation received at the detector array is dependent upon the attenuation of the x-ray beam by the object. Each detector element of the array produces a separate electrical signal that is a measurement of the beam attenuation at the detector location. The attenuation measurements from all the detectors are acquired separately to produce a transmission profile.

In known third generation CT systems, the x-ray source and the detector array are rotated with a gantry within the imaging plane and around the object to be imaged so that the angle at which the x-ray beam intersects the object constantly changes. A group of x-ray attenuation measurements, i.e., projection data, from the detector array at one gantry angle is referred to as a "view". A "scan" of the object comprises a set of views made at different gantry angles, or view angles, during one revolution of the x-ray source and detector. In an axial scan, the projection data is processed to construct an image that corresponds to a two-dimensional slice taken through the object. One method for reconstructing an image from a set of projection data is referred to in the art as the filtered back projection technique. This process converts the attenuation measurements from a scan into integers called "CT numbers" or "Hounsfield units", which are used to control the brightness of a corresponding pixel on a cathode ray tube display.

A main objective of cardiac CT applications is to perform calcification scoring, a diagnostic procedure in which an amount of calcification present in a patient's heart is estimated. At least one known CT imaging system requires about 0.5 s to complete data acquisition for an image. Although this speed is satisfactory for general imaging purposes, it is not fast enough to avoid motion-induced image artifacts in cardiac CT imaging, in which a typical cardiac cycle is about 1.0 s long. These artifacts present major problems for cardiac calcification scoring.

At least one other known CT imaging system reduces motion-induced image artifacts by acquiring data rapidly enough to effectively freeze cardiac motion. This imaging system employs a scanning electron beam to generate a moving source of x-rays rather than an x-ray source and detector on a rotating gantry. However, CT imaging systems employing scanning electron beams are quite expensive and are not available at many hospitals.

It would therefore be desirable to provide methods and apparatus that overcome motion-induced artifacts produced in images acquired by CT imaging systems having relatively slow scanning and detection systems such as rotating gantries. It would also be desirable to provide cardiac calcification scoring methods and apparatus utilizing such CT imaging systems. It would further be desirable to provide

methods and apparatus that can readily identify and score calcification from the small incremental x-ray attenuation produced by small amounts of calcification.

BRIEF SUMMARY OF THE INVENTION

There is therefore provided, in one embodiment of the present invention, a method for producing CT images of a patient's heart suitable for calcification scoring, in which the heart has a cardiac cycle. The method includes steps of acquiring data representative of a first scout-scanned CT image of physical locations of the patient's body including at least a portion of the patient's heart at phases $\phi_1(L)$ of the cardiac cycle, acquiring data representative of a second scout-scanned CT image of the physical locations of the patient's body including at least a portion of the patient's heart at phases $\phi_2(L)$ of the cardiac cycle different from $\phi_1(L)$ at physical positions L of interest, and determining a difference image from the acquired data representative of the first scout-scanned CT image and the acquired data representative of the second scout-scanned CT image data. It is not necessary that $\phi_1(L)$ and $\phi_2(L)$ be constant as a function of position L.

The above described embodiment overcomes motion-induced image artifacts by making calcification signals more readily observable as a change between images. Moreover, even small amounts of calcification are readily identifiable and quantifiable, because much larger variations in x-ray attenuations that would otherwise hide calcification deposits are canceled out.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a pictorial view of a CT imaging system.

FIG. 2 is a block schematic diagram of the system illustrated in FIG. 1.

FIG. 3 is a representation of a portion of the system illustrated in FIG. 1 showing a patient translated by the table shown in FIG. 1 while the x-ray source and detector remain stationary during a scout scan.

FIG. 4 is a representation of a scout image showing time relationships between columns of data that make up the scout image.

FIG. 5 is a simplified graphical representation of an electrocardiogram, showing times represented by columns in the scout image of FIG. 4 and a relationship between a first scout image and a second scout image in one embodiment of the present invention.

FIG. 6 is a simplified graphical representation of intensity vs. detector location in a column of a first scout scan.

FIG. 7 is a simplified graphical representation of intensity vs. detector location in a column of a second scout scan corresponding to the column represented in FIG. 6.

FIG. 8 is a representation of a difference between intensities as a function of detector location between data such as that represented in FIG. 6 and FIG. 7, whereby a calcium signal is isolated in one embodiment of the present invention. FIGS. 6, 7, and 8 should not necessarily be assumed to be drawn to the same scale.

FIG. 9 is a representation of pixels of an image analyzed using image processing techniques in an embodiment of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

Referring to FIGS. 1 and 2, a computed tomograph (CT) imaging system 10 is shown as including a gantry 12

representative of a "third generation" CT scanner. Gantry 12 has an x-ray source 14 that projects a beam of x-rays 16 toward a detector array 18 on the opposite side of gantry 12. Detector array 18 is formed by detector elements 20 which together sense the projected x-rays that pass through an object 22, for example a medical patient. Detector array 18 may be fabricated in a single slice or multi-slice configuration. Each detector element 20 produces an electrical signal that represents the intensity of an impinging x-ray beam and hence the attenuation of the beam as it passes through patient 22. During a scan to acquire x-ray projection data, gantry 12 and the components mounted thereon rotate about a center of rotation 24.

Rotation of gantry 12 and the operation of x-ray source 14 are governed by a control mechanism 26 of CT system 10. Control mechanism 26 includes an x-ray controller 28 that provides power and timing signals to x-ray source 14 and a gantry motor controller 30 that controls the rotational speed and position of gantry 12. A data acquisition system (DAS) 32 in control mechanism 26 samples analog data from detector elements 20 and converts the data to digital signals for subsequent processing. An image reconstructor 34 receives sampled and digitized x-ray data from DAS 32 and performs high speed image reconstruction. The reconstructed image is applied as an input to a computer 36 which stores the image in a mass storage device 38.

Computer 36 also receives commands and scanning parameters from an operator via console 40 that has a keyboard. An associated cathode ray tube display 42 allows the operator to observe the reconstructed image and other data from computer 36. The operator supplied commands and parameters are used by computer 36 to provide control signals and information to DAS 32, x-ray controller 28 and gantry motor controller 30. In addition, computer 36 operates a table motor controller 44 which controls a motorized table 46 to position patient 22 in gantry 12. Particularly, table 46 moves portions of patient 22 through gantry opening 48 along a z-axis. In some of the embodiments described below, cardiac cycles are measured utilizing EKG machine 50.

An amount of calcification present in the cardiac system of patient 22 is reliably estimated from scout images taken with CT imaging system 10 in one embodiment of the present invention. Patient 22 is instructed to hold his or her breath while images of the heart of patient 22 are scanned by CT imaging system 10 in a scout imaging mode of operation. Because patient 22 is holding his or her breath, the only moving object within the scan field of view is the heart of patient 22. Data for two scout scans are obtained, and a difference between the data for the two images is used to remove non-moving body structure and highlight calcification, as explained below.

In one embodiment of the invention and referring to FIG. 3, scout-scanned data of patient 22 is acquired. Scout-scanned data is acquired by moving table 46 through gantry opening 48 in a z-direction while gantry 12 is held stationary. Thus, x-ray source 14 and detector array 18 are stationary while data such as that represented in FIG. 4 is acquired. The acquired data represents a CT image of a region of the body of patient 22. Each column of scout image 52 is representative of x-ray attenuation data obtained at a certain instant of time. In one embodiment, each column of data, such as column 54 and column 56, is acquired in approximately 1 millisecond. Thus, each successive column of acquired data is sampled at a slightly different time. In FIG. 4, for example, column 54 is acquired at time t and at a displacement p from a starting position of the scout scan in

a z-axis direction. Column 56, which is immediately adjacent to column 54, is acquired at time t+Δt, where Δt is approximately 1 millisecond. Column 56 is located at displacement p+Δp from the start of the scout scan. An entire scout scan image 52 sufficient for the present embodiment is taken in about two or three seconds. Data representing physical locations of a portion of the body of patient 22 including at least a portion of heart 58 is acquired and used for cardiac calcification scoring.

Data representing a second scout image (not shown) is also acquired. The second scout scan image is acquired in a manner that ensures that corresponding columns of the second scout scan are taken at times during which heart 58 is in a different phase of first scout image 52. In this manner, data representative of a first and a second scout-scanned CT image of physical locations of the body of patient 22 are obtained. Data for each physical location is obtained at different phases of the cardiac cycle in the two images.

For example, referring to FIG. 5, column 54 of first scout image 52 is acquired at a time corresponding to phase 60 just prior to systole 62 of EKG signal 64. (EKG signal 64 is obtained by monitoring heart 58 of patient 22 using EKG machine 50.) Column 56 of scout image 52 is acquired at a time corresponding to phase 66. The second scout image is taken a few seconds after first scout image 52. By selection of a start time for its acquisition, corresponding columns of the second scout image are acquired at phases 68 and 70, immediately after systole 72. Both scout images are acquired at the same rate starting from the same position of patient 22 and table 46 moves at the same speed and in the same direction for each scout image acquisition in this embodiment. Thus, starting each scan at a different phase of EKG signal 64 is sufficient to ensure that corresponding columns in the two scans represent different phases of heart 58, assuming heart 58 is beating at a constant rate. This assumption is applicable because the entire procedure is completed in only a few seconds.

In one embodiment, scout scans are manually started. For example, phases of EKG signal 64 from EKG machine 50 are manually monitored to determine trigger times to begin each scout-scanned data acquisition. In another embodiment, scans are started automatically. For example, computer 36 of CT imaging system 10 is configured to receive and monitor EKG signal 64 or an equivalent to determine trigger times.

During scanning, patient 22 holds his or her breath and remains as still as possible to minimize differences between the first and the second scout images other than those related to heart movement. It is reasonable to request patients to hold their breath during the scanning and feasible for patients to comply with such requests due to the brevity of the procedure.

It will be observed that data for each scout image, for example, image 52, is a composite representing different phases of heart 58. Each physical location L represented by data of the first scout image is acquired at a phase $\phi_1(L)$ of the cardiac cycle. For the second scout image, data for location L is acquired at a phase $\phi_2(L)$, where $\phi_1(L) \neq \phi_2(L)$. Because of the amount of time taken by table 46 to travel from one end of each scout scan to the other, neither ϕ_1 nor ϕ_2 are constant across each scout image. However, their difference at any location L is constant, or nearly so. The present invention advantageously uses this difference to highlight cardiac calcification.

Columns of intensity (or equivalently, attenuation) data is obtained by detector array 18 while table 46 moves to obtain